Climate Change Case Study:

Flood risk arising from future precipitation changes in Gleniti, Timaru

Prepared for the NZ Climate Change Office (Ministry for the Environment) by OPUS International Consultants Limited in conjunction with Timaru District Council

Executive Summary

As part of its portfolio of climate change work, the New Zealand Climate Change Office (NZCCO) within the Ministry for the Environment (MfE) has begun a programme to assist regional councils and territorial authorities to better understand and take into account climate change effects when carrying out their day-to-day operations. In particular, the programme aims to develop guidance materials for local authorities to assist them in assessing and managing the risks of climate change in their planning processes. While this report is geographically specific in its scope, it is expected that many of the issues, challenges, and methodologies relating to flood risk management within a climate change framework presented here will also be applicable in other regions and catchments.

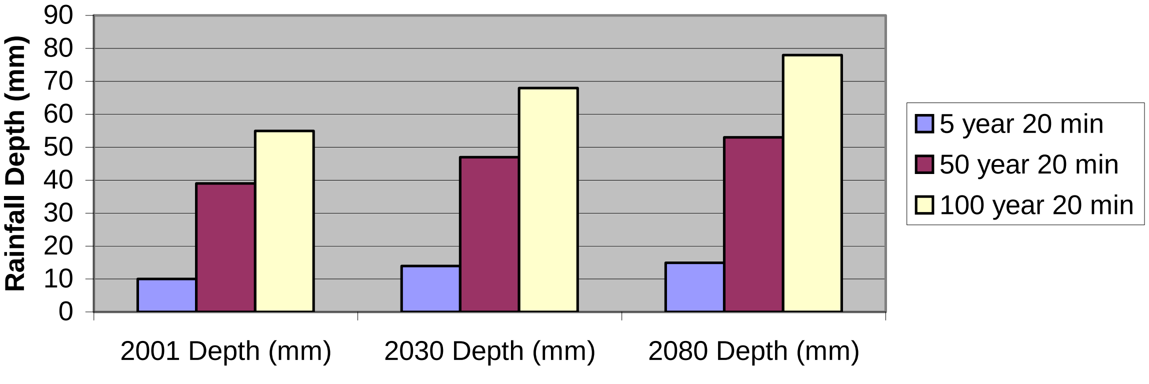
As part of its case study series, the New Zealand Climate Change Office commissioned Opus International Consultants (Opus) to assess flood risk arising from possible future precipitation changes in Gleniti, Timaru, due to climate change effects. This report describes the projected climate change effects, discusses the outcomes of a re-worked flood model which takes into account these effects, and assesses the implications for two of the catchments.

The objectives of this report are to:

- Estimate the projected rainfall in 2030 and 2080 and compare them to 2001 rainfall.
- Assess the implications of the increased flood risk in the catchments posed by the projected future rainfall changes.
- Produce an industry best practice example report available for public access that will help users get a feel for the relevance of incorporating climate change scenarios in their stormwater planning. It should also demonstrate the relative extra work and cost required in carrying out a climate change assessment as part of a bigger stormwater planning exercise.

Projected **upper bound** rainfall estimates are derived for 2030 and 2080 from the draft CCO-commissioned *Overview of Climate Change Effects and Impacts Assessment.* A *Guidance Manual for Local Government in New Zealand,* (NIWA 2003), which at the time of writing is not yet available for publication. The graph below shows a summary of the projected increases in a 20 minute duration event. Rain depths for other storm durations were also calculated.

Figure ES1 Rain Depth Comparison for five year 20 minute: 2001, 2030 and 2080



Two catchments were selected from the 2001 study *Timaru District Council, Flood Mitigation Study for Waimataitai Catchment, Timaru City,* August 2001 for the Waimataitai (super) catchment. The first catchment (the upper catchment) is a 100 ha proposed development bounded by Gleniti Road and Pages Road and the second (the lower catchment) includes basins 1-6 in the area downstream of the development but also includes some of the upper catchment. The upper catchment had a time of concentration (tc) of 20 minutes while the lower had a tc of one hour. The Waimataitai River section downstream of this catchment influences the tc (in the 2001 study, flooding from the Waimataitai River became more critical than from the urban catchments and so the critical tc most closely matched the river section). For the purposes of comparison, we used that tc even though it is not necessarily critical for the urban part of this catchment. The hydrologic and hydraulic models used in 2001 were rerun under the projected 2030 and 2080 rain depth scenarios.

The results are discussed in a risk management framework. They showed flow volume increases in proportion to rain depth increases.

The increased rain depths projected for 2030 and 2080 cause flood depths, flows and volumes to increase in both the study catchments. However, the increases are not significant enough to cause an increase in damage costs. The reasons for this may be unique to each catchment and are discussed below.

In the **upper catchment**:

- The detention dams are all designed at a generic height of 2m. This allows a reasonable freeboard in most cases. For example, the maximum depth of water backing up behind detention dam C1 is around 1m and many of the others are around 1.2m-1.7m. The average (over all the detention dams) maximum depth change for a five year event is 6% for 2030 and 18% for 2080. In a 50 year event the increases are 6% for 2030 and 13% for 2080. The following table illustrates how the factor of safety against dam overtopping reduces in 2030 and 2080 for both the five year and 50 year events. The factor of safety has been averaged over all detention dams.

Table 6.1 Average factor of safety against dam overtopping in the upper catchment

Year / Rain event	2001	2030	2080
Five year 20 minute	2.5	2.3	2.0
50 year 20 minute	0.6	0.5	0.4

- The discharge culverts are all a generic 450 mm diameter. These could have been individually sized to optimise flow conditions and ponding depths and to provide an additional margin of safety.

- The proposed housing developments will be well set back from the waterway gullies. Therefore, any flooding that would occur from within the gully/detention dam system due to an extreme rain event is unlikely to cause property damage.

The net effect of these three design features is to build in a factor of safety. As discussed in Section 6, if the design had only allowed for an appropriate freeboard by today's standards then this catchment would suffer an increased flood risk in 2030 and 2080.

Note that the assessment of the change in flood risk and its effect on safety margins is limited by some uncertainty in the rainfall base data. This data was extrapolated from historic records and used to estimate 50 and 100-year return periods. We estimate that the proposed detention dams, culverts and housing development in all cases provide a sufficient margin of safety to accommodate the uncertainty of the current flood risk.

In the **lower catchment**:

- The projected flood depth increases of 60 mm to 120 mm in 2030 and 2080 are not significant enough to threaten any more properties than in 2001. In many cases, the habitable spaces in potentially threatened houses are sufficiently elevated from the basins.

As with the upper catchment above, the effect of raised houses is to build in a factor of safety. There may be existing flood basins in other parts of Timaru, which are 'right at the limit' with only a minimal factor of safety. It is these areas that would suffer an increased flood risk in 2030 and 2080.

It is important to note that the flow rates and depths are generated from projected **upper bound** rainfall depth predictions. If these rainfall changes occur as predicted, the net result is that stormwater assets designed today should have a greater in-built factor of safety than is currently used. Most stormwater pipes, drains and structures should be designed for 50 years plus.

However, the most likely future scenario is likely to lie somewhere between no change and an upper bound estimate. For planning purposes, it may be most practical to plan as a minimum for the midway between no change and the upper bound scenario. For other planning situations, if an initial screening analysis suggests that margins of safety could be substantially reduced or even breached due to climate change, the full range of future scenarios should be explored and a more complex analysis of future changes in heavy rainfall and return periods may be required.

We recommend that:

1. **Climate change research continues so that the rainfall predictions for Timaru may be further refined. The findings in this study are based on an initial screening analysis and our conclusions are qualified by uncertainties in the current distribution of heavy rainfall events for the catchment in question.**

2. **In the meantime, assets with design life exceeding 50 years should be designed using at least half the upper bound predicted rain depth increases. This equates to 6% for the five year event and 14% for the 50 year event in the Canterbury region.**

3. **There be no change to the proposed stormwater system for the Gleniti development. The built-in margin of safety is large enough to accommodate the expected increase in heavy**

rainfall events even for the upper bound of expected changes. The same applies to the lower catchment.

Table of Contents

1 Introduction

In this section we introduce the report context and objectives and summarise the report structure.

The New Zealand Climate Change Office (NZCCO) within the Ministry for the Environment (MfE) commissioned Opus International Consultants (Opus) to assess flood risk arising from possible future precipitation changes in Gleniti, Timaru. This report describes the projected changes, discusses the outcomes of a reworked flood model and assesses the implications for two of the catchments. The first catchment is a proposed development in the Gleniti area and the second is a piped catchment downstream of the development. One of the key tasks in this study was to rework part of the original hydraulic model used in a study carried out in 2001[1]. In this study Opus prepared catchment management plans for three large and several small urban catchments in Timaru city. The study covered the following: water quality issues, hydraulic modelling of stormwater reticulation and flood paths, flood hazard identification and treatment options to reduce flood risk.

The objectives of the current report are to:

- Estimate the projected rainfall in 2030 and 2080 and compare them to 2001 rainfall.
- Assess the implications of the increased flood risk in the catchments posed by the projected future rainfall changes.
- Produce an industry best practise example report available for public access that will help users get a feel for the relevance of incorporating climate change scenarios in their stormwater planning. It should also demonstrate the relative extra work and cost required in carrying out a climate change assessment as part of a bigger stormwater planning exercise.

This report should be read in conjunction with the 2001 report[1]. Much of the background to this study and context can be found in the earlier report.

1.1 Report Structure

The balance of the report is structured as follows:

SECTION		DISCUSSION
2	Projected rainfall for Gleniti in 2030 and 2080	Discusses projected rainfall changes for Timaru in 2030 and 2080.
3	Catchment detail and hydraulic model	Discusses the catchment characteristics and explains how the hydraulic model was set up and run.

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[1] *Timaru District Council. Flood Mitigation Study for Waimataitai Catchment, Timaru City.* August 2001

4	The flood risk framework	Introduces a flood risk framework in terms of SNZ HB4360: 2000.
5	The context	Establishes the flood risk context in the two catchments.
6	Identify the flood risk	The future rainfall profile is used as the input into a computer model. The new risk profile is generated.
7	Analyse risks	Analyses the risk in terms of likelihood and consequences. Compares 2001 consequences with 2030 and 2080 consequences.

2 Projected Rainfall for Gleniti in 2030 and 2080

In this section we present upper bound rainfall depth frequency estimates for Timaru City. This is based on analysis of data in the draft Guidance Manual[2]*.*

2.1 Introduction

In the 2001 study, Opus analysed rainfall data for Gleniti from 1977-98. The main outcome for the study was the rainfall data in Table 2.1 below.

Table 2.1. Gleniti (1977-98) Rainfall Depth Frequency Estimates (mm)

Return Period (years)	Storm Duration								
	5 min	**10 min**	**20 min**	**30 min**	**1 hr**	**2 hr**	**6 hr**	**12 hr**	**24 hr**
2.33	4	5	7	9	13	18	29	39	53
5	6	7	10	12	18	27	43	55	77
10	12	13	14	16	26	35	56	72	95
20	14	18	27	31	37	43	67	89	112
50	15	23	39	41	47	54	82	112	135
100	23	25	55	60	61	62	94	129	152

One of the key outcomes of this study is to predict rainfall intensities in 2030 and 2080. This data is then used to produce a new flood risk profile.

The Guidance Manual was used as a basis for calculating future rainfall intensities for Gleniti. In line with the scope of the study and for simplicity we focused on the province of Canterbury rather than the suburb of Gleniti. The projected intensities for 2030 and 2080 are presented below together with a discussion on how they were derived and their accuracy.

Note that we have used the words *upper bound* rainfall scenario. The draft Guidance Manual states that there could be up to a four-fold increase in heavy rainfall frequency in 2080; whereas the increases that we calculated in this study are less than two. This is reasonable because the increases will vary across the regions and also depend on the rainfall characteristics of specific catchments.

2.2 Derivation of Projected Rainfall

Table 5.1 in the draft Guidance Manual describes two possible methods to develop heavy rainfall scenarios under projected climate change. The first method, *Initial Screening Studies*, recommends using Table 5.2 (in the draft Guidance Manual) "projected changes per degree of warming in extreme rainfall". The second method, *Detailed Studies*, recommends obtaining assistance from NIWA to undertake a site-specific Gamma Function analysis as outlined in Appendix 3 of the draft Guidance Manual.

The Initial Screening Study method has been applied and the projected changes (percentage) per degree of warming in extreme rainfall (Table 2.3) are added to the rainfall depth frequency estimates (Table 2.1).

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[2] *Overview of Climate Change Effects and Impacts Assessment.* A *Guidance Manual for Local Government in New Zealand,* (NIWA 2003) – a draft NZCCO report not yet published.

Table 2.2 Projected changes per degree of warming in extreme rainfall (%)

Duration	ARI (years)										
	2	**5**	**10**	**20**	**30**	**50**	**60**	**70**	**80**	**90**	**100**
5 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
20 minutes	7.6	7.6	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
30 minutes	7.3	7.4	7.5	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.6
1 hour	6.8	7.1	7.2	7.2	7.2	7.3	7.3	7.3	7.3	7.4	7.4
2 hours	6.4	6.7	6.8	6.9	6.9	7.1	7.1	7.1	7.1	7.1	7.1
6 hours	5.7	6.1	6.3	6.5	6.5	6.6	6.6	6.7	6.7	6.7	6.7
12 hours	5.2	5.8	6.0	6.2	6.3	6.4	6.4	6.4	6.4	6.5	6.5
24 hour	4.8	5.4	5.7	5.9	6	6.1	6.1	6.1	6.2	6.2	6.2
48 hour	2.8	2.5	2.5	2.4	2.4	2.4	2.3	2.3	2.3	2.3	2.3
72 hour	2.9	3.1	3.1	3.2	3.3	3.3	3.4	3.4	3.4	3.4	3.4

This table has been adapted from Table 5.2 in the draft Guidance Manual

The projected changes in Table 2.2 are the best available for heavy rainfall events (pers. comm. Horace Freestone, Opus and David Wratt, NIWA). Estimates of changes in seasonal and annual rainfall are readily available from a number of sources but this is the first attempt at providing an indication of possible increases or decreases in rainfall depth during heavy rainfall events.

The draft Guidance Manual projects changes for only 24, 48 and 72 hour duration events. However, after discussion with NIWA scientists, five and 10 minute duration values have been added (a constant 8% change across all durations). A logarithmic interpretation between the five minute and 24 hour duration was used to determine the projected changes (pers. comm. Horace Freestone, Opus and David Wratt, NIWA) for all durations. A revised table will appear in the Guidance Manual (when finalised) detailing durations shorter than 24 hours.

Tables 2.4 and 2.5 in the draft Guidance Manual provide projected changes in seasonal and annual mean temperature for the Canterbury region for 2030 and 2080. The maximum increase in temperature **(as a worst case scenario)** from these tables was 1.8°C for 2030 and 3.9°C for 2080. These values were applied to the projected changes per degree of warming and the percentage change in rainfall amount for each return period calculated as in table 2.3 for the 20 minute, one hour and two hour durations. For example; for a 100 year return period rainfall event there will be a 13.7 % increase in the total rainfall amount by 2030 and a 29.6 % increase by 2080.

Table 2.3. Percentage change in heavy rainfall totals in Canterbury – 20 minute, one hour and two hour durations

	20 minute		One hour		Two hour	
Return period (yrs)	**2030 % change**	**2080 % change**	**2030 % change**	**2080 % change**	**2030 % change**	**2080 % change**
5	10.0	30.0	12.8	27.7	12.1	26.1

50	12.8	31.0	13.1	28.5	12.8	27.7
100	14.5	31.0	13.3	28.5	12.8	27.7

The percentage change in heavy rainfall for each return period was applied to the Gleniti depth duration frequency estimates to produce projected rainfall depth duration frequency estimates for 2030 and 2080 as outlined in Table 2.4 below. Note that these are based on the maximum projected temperature change for 2030 and 2080.

2.3 Summary of Findings and Recommendations

The following summary table shows the projected rainfall depths for 2030, and 2080 in a 20 minute and one hour duration storm. These are compared to the 2001 values from the 2001 study. Note that the 20 minute storm was found to be the critical storm for the upper catchment and one hour for the lower catchment.

Table 2.4 Timaru rainfall depth frequency estimates (mm) for 20 minute and one hour storms. 2001, 2030 and 2080

Return Period	2001			2030			2080		
	% Increase from 2001	Depth (mm) 20 min	Depth (mm) 1hr	% Increase from 2001	New Depth (mm) 20 min	New Depth (mm) 1hr	% Increase from 2001	New Depth (mm) 20 min	New Depth (mm) 1hr
5	0	10	18	13	11	20	28	13	23
50	0	39	47	13	44	53	28	50	60
100	0	55	61	13	62	69	28	70	78

Figure 2.2. Rain depth comparison for five year 20 minute: 2001, 2030 and 2080

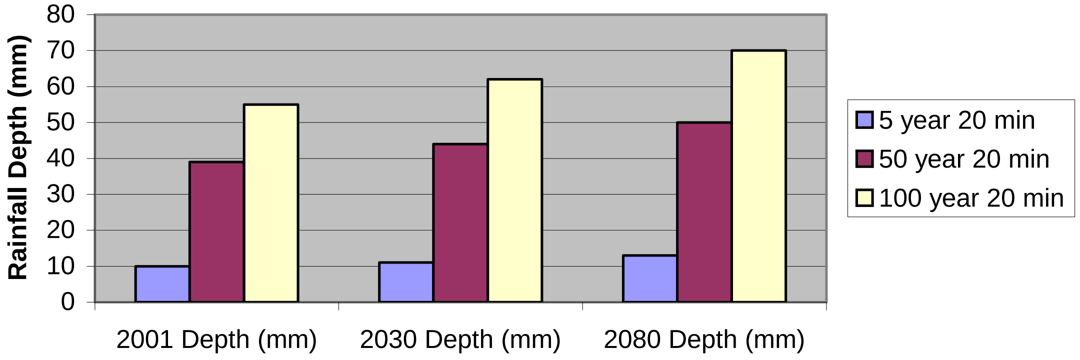
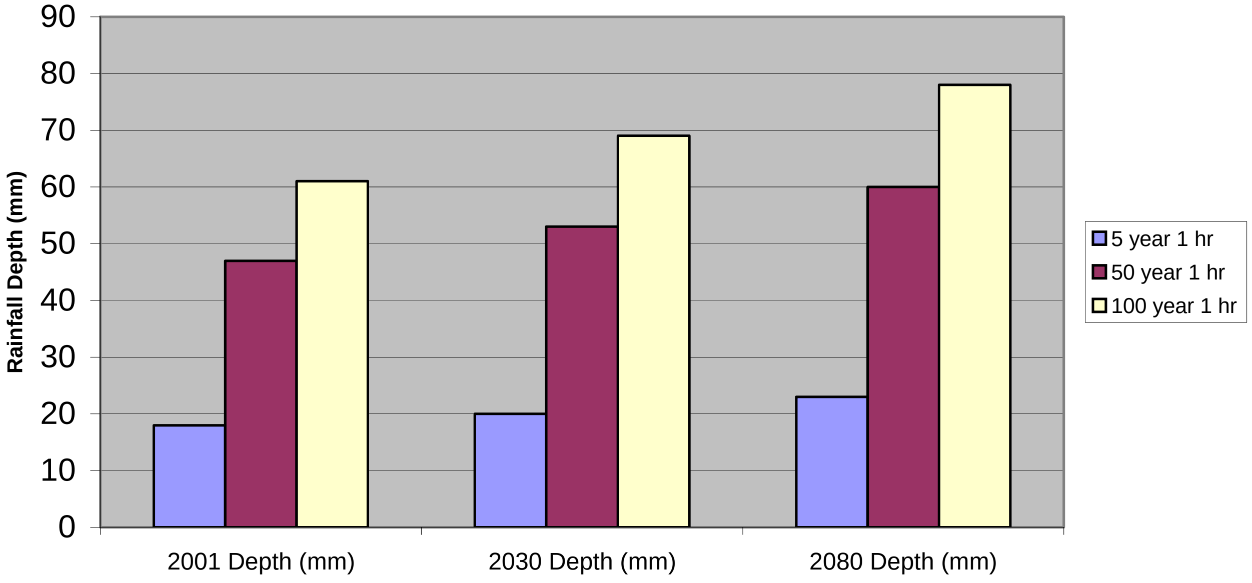


Figure 2.3. Rain depth comparison for one hour storms: 2001, 2030 and 2080



2.4 Data and Accuracy Limitations

Obviously, no one can predict the future with absolute confidence and the actual rain depth scenarios will depend on a number of factors; many of which may be unforeseen today. These limitations are discussed in the NZCCO draft Guidance Manual on Climate Change. Our work in this report is also limited by these predictions but we have tempered our recommendations in an attempt to ensure that they are not only reasonable but also practical.

Note that the assessment of the change in flood risk and its effect on safety margins is limited by some uncertainty in the rainfall base data. This data was extrapolated from historic records and used to estimate 50 and 100-year return periods so the estimate of the rainfall intensity for those longer return periods carries a substantial uncertainty, even for the present climate conditions.

Further modelling limitations are discussed in our 2001 report.

3 Catchment Detail and Hydraulic Model

The purpose of this section is to describe the two study catchments and to explain how the 2001 model was reworked in the light of the projected 2030 and 2080 rainfall intensity changes.

3.1 Background and Catchment Selection

In the 2001 study, we calculated runoff for five year, 50 year and 100 year events at various storm durations. The 20 minute duration was found to be critical in the upper catchment and the one hour event in the lower catchment. In this study we rebuilt and re-ran the models as follows:

Two catchments were selected from the 2001 study for the Waimataitai (super) catchment. The first catchment (the upper catchment) is the 100 ha proposed development bounded by Gleniti Road and Pages Road and the second (the lower catchment) includes basins 1-6 in the area downstream of the development but also includes some of the upper catchment (see Figure 3.1).

The reason for the choice of these two catchments is discussed below.

3.1.1 Reasons for including the upper catchment – Gleniti proposed urban development

This block of land is strategically important to TDC because it is an area of future urban growth for the city and because it impacts on downstream infrastructure such as stormwater reticulation. This proposal and the location of the detention dams are shown schematically in Figure 3.2.

TDC are interested in knowing whether the current stormwater design will adequately deal with future design flows. As the block is currently in the planning and design phase, there is still time to make design changes prior to construction (if required).

Opus has prepared a development plan for the block. Interesting drainage features of the plan include minimal earthworks and the inclusion of natural drainage measures to minimise stormwater runoff including:

- Pipe-less solutions (as far as possible) such as swales, check detention dams, waterways and subsoil drainage.
- More retention and lower velocity flow in roadside swales (than would be expected in a conventional situation).
- Encouraging the development of rain gardens (low lying areas planted out with a drain or soil soakage below) on private properties.

3.1.2 Reasons for including the lower catchment

This area includes basins 1 – 6 in the area downstream of the proposed urban development plus the upper catchment itself. In fact, the upper catchment is a subset of the lower catchment.

We have chosen this area because we were able to remodel it under future rainfall scenarios and provide flood depth and direct cost comparisons with 2001 data. In the original study, our hydraulic model alerted us to areas in the 50 year event where water either spilled out or was unable to enter the piped system at manholes. We then modelled the surrounding areas either as flow paths or basins. The actual ground profiles were based on ground survey. Basins 1-6 were locations where surcharged or backed up flow would pond, as described above.

3.2 Critical Storm Durations

The upper catchment has a time of concentration (tc) of around 20 minutes and the lower closer to one hour. The Waimataitai River section downstream of this catchment influences the tc (in the 2001 study, flooding from the Waimataitai River became more critical than from the urban catchments and so the critical tc most closely matched the river section). For the purposes of comparison we used that tc even though it is not necessarily critical for the urban part of this catchment.

3.3 MOUSE Modelling

The two catchments were modelled using the MOUSE urban drainage modelling package developed by the Danish Hydraulic Institute. This package incorporates two components - a hydrologic component, to predict surface runoff from rainfall inputs, and a hydraulic component, to simulate the passage of surface runoff through a piped drainage network with parallel overland flow paths where appropriate.

Both catchments were remodelled under the projected 2030 and 2080 rainfall profiles (see Section 2). The MOUSE model estimated runoff volumes and flood profiles for each catchment. These were compared to the 2001 profiles. See sections 4-7 for discussion of results within a risk framework.

Catchment runoff (in the hydrological model) was estimated using the rainfall/runoff modelling capability in MOUSE as follows:

1. Rain intensity, duration and storm pattern inputs for the above storms were calculated as described in Section 2.
2. Each subcatchment was assigned a time of concentration, which describes how quickly rainfall flows off the subcatchment and into the pipe network system.

3. The following physical attributes have been considered in calculating the overall runoff coefficients:

   - Soil type
   - Percent impervious cover
   - Subcatchment slope
   - Rainfall intensity

Pipe and channel flow (in the hydraulic model) was calculated in MOUSE as described below. Because there were two models[3] the description below covers common elements and elements which are unique to each catchment. Both hydraulic models[3] share the following common elements:

1. Physical model data such as pipe data.

2. Cross-section data for overland flow paths and gully waterways as described in Appendix A.

Unique aspects for the *downstream catchment* include:

1. The pipework part of the model was calibrated against two actual storms; one in 1986 and the other in 1999. The calibration showed good agreement between the model and actual network performance (see the 2001 report). Note that we updated the calibrated model from 2001.

2. The reticulated network includes a section of overland flow.

3. The reticulated network is generally only designed for small events such as the five year storm. In other storms, stormwater will surcharge at manholes and sumps or will simply not be able to enter the system as described in Section 3.1.2.

Unique aspects for the *upstream catchment* include:

1. Gully waterways, basins, detention dams and culverts.

2. Hydraulic modelling where MOUSE models the actual situation of water building up behind 2m high detention dams with controlled release via a 450mm diameter culvert.

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[3] One hydrologic (rainfall) and one hydraulic (flow) model for each catchment.

4 The Flood Risk Framework

This section introduces the flood risk in terms of the framework described in SNZ HB 4360: 2000 Risk Management for Local Government.

4.1 Introduction

As with the 2001 report, the flood risk needs to be quantified and analysed in terms of likelihood and consequence and ultimately, options for treatment assessed. This report does not specifically deal with treatment options; its purpose is to compare the consequences of flooding under projected 2030 and 2080 rainfall with those assessed for 2001 in the previous study.

The following sections deal with these aspects in a risk management framework. This framework is based on the process in SNZ HB 4360: 2000 *Risk Management for Local Government* and is shown diagrammatically in Figure 4.1.

4.2 What is Risk?

Risk is the chance of something happening which will have an impact on objectives (in this case to manage flooding). It is measured in terms of consequence and likelihood. The concept of risk has three elements:

- the perception that something could happen
- the likelihood of something happening
- the consequences of it happening.

In the stormwater management context, the level of risk is the combination of the likelihood of floods occurring, and the consequences if it does occur. Action taken to manage or treat the flood risk, and therefore change the level of risk, needs to address the likelihood of any event occurring, or the consequences if it does occur, or both. Flood risk reduction measures are not discussed in this report. See the 2001 report for an example of this type of strategy.

4.3 Structure of Sections 5-7 (Based on Figure 4.1)

4.3.1 Context - Section 5

The goals and objectives of the risk management strategy are defined in terms of key outcomes for TDC.

4.3.2 Identify the Flood Risk - Section 6

The flood risk is defined by analysing outputs from the two hydraulic models for the 2030 and the 2080 rainfall scenarios. One of the key inputs into the models was the projected rain data (as discussed in Section 2). The background to the model is discussed in Section 3. The key outputs in this section are:

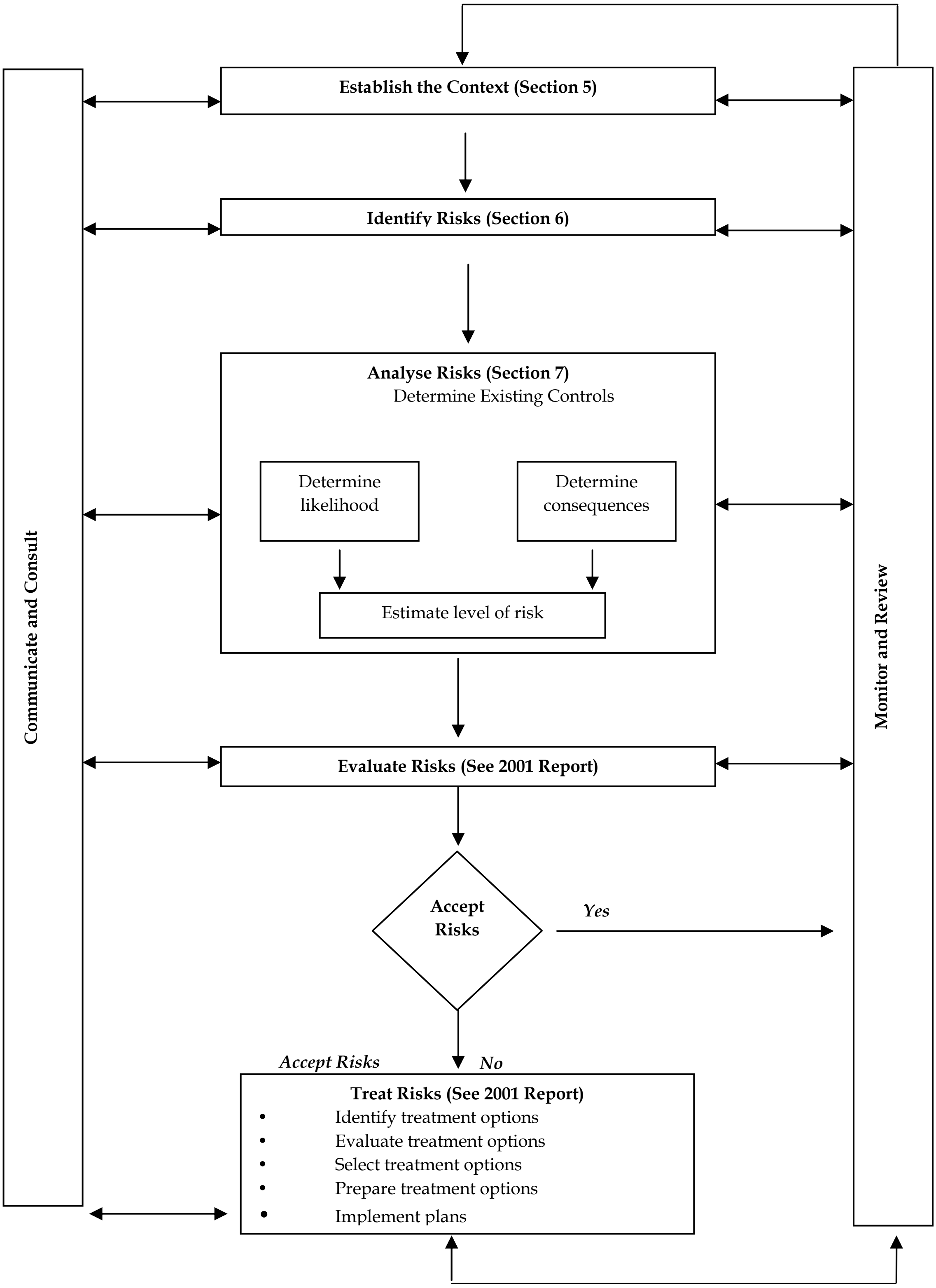
- Tables and graphs comparing flood depths, flows and volumes in 5 and 50 year floods.
- Flood hazard maps showing the extent of flooding graphically in the lower catchment.

4.3.3 Analyse the Risk - Section 7

In this section, the likelihood of flooding and its consequence is discussed. As the catchments are mainly residential, most of the consequence will be the financial cost of property damage. Other costs such as infrastructure damage and disruption costs are also discussed.

Figure 4.1: Risk Management Process

(SNZ HB 4360:2000)



5 The Context

The Context for this study has been established in previous sections and is the first element in the risk framework. See Figure 4.1.

To help understand the context of the risk we first need to know the objectives. NZCCO and TDC undertook this study with the following objectives:

1. A better understanding on a city wide basis of:
    - Whether rainfall depths and intensities are likely to change in the future due to climate change effects.
    - As above; if change occurs what is the effect?
2. A better understanding of two catchments as to:
    - The hydraulic performance of the stormwater reticulation and overland flow paths in 2030 and 2080.
    - What the new flood risk will be and its implications in terms of damage and disruption.

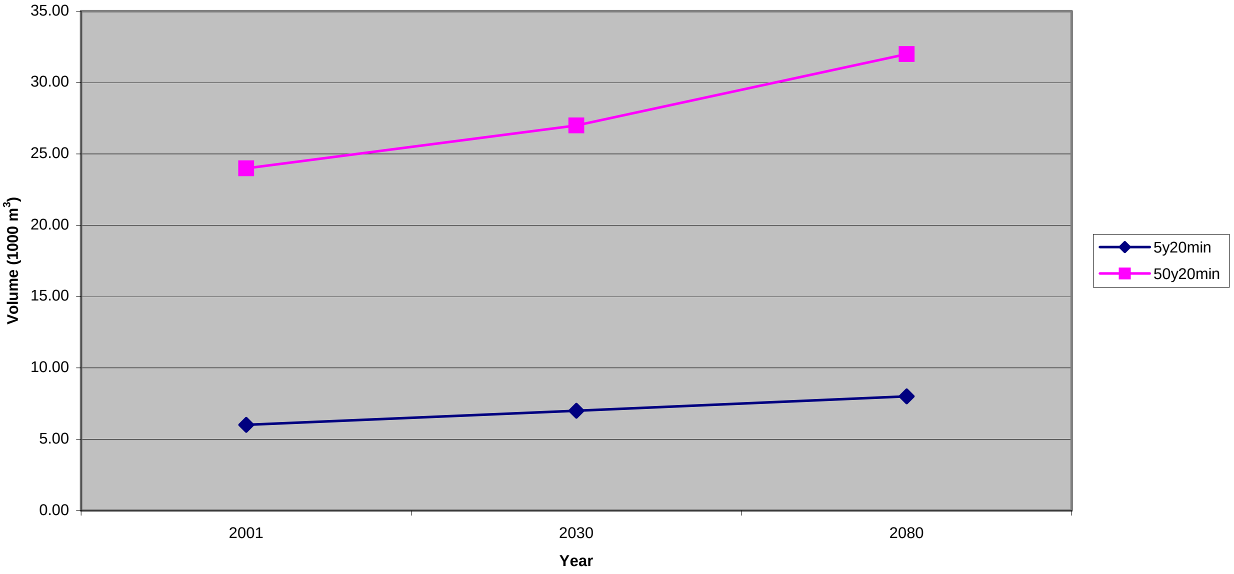
6 Identify The Flood Risk

In this section the flood risk is defined in terms of likely flood depths and extent of property damage for the 50 year and 100 year design storms in 2030 and 2080 and then compared to 2001.

6.1 Findings for the Upper Catchment

As discussed in Section 3 there are two parts to the hydraulic model. The first is the hydrologic (rainfall) part and the second is the hydraulic part (flows within reticulation). Runoff is the word used to describe the flow "running-off" the ground. Note that not all the rainfall runs off: some is lost to ground soakage. Figure 6.1 below shows the increasing trend of the total volume of runoff (in five year and 50 year events) projected to occur until 2080.

Figure 6.1: Total Catchment Runoff Volume



Runoff volume is (approximately[4]) directly related to the volume of rainfall by a runoff coefficient C if the rainfall depth is uniform over the catchment (this is a reasonable assumption for the small catchment areas considered in this study). Therefore the runoff volume increases in 2030 and 2080 by the same rate as the increase in rainfall depth (13% for 2030 and 28% for 2080).

As shown in Figure 3.2, the catchment comprises a series of subcatchments draining into four gully systems labelled A, B, C and D. Within each of these gullies, we propose a series of detention dams with a 450 mm diameter culvert pipe. The idea is that the pipe will form a throttle, water will build up behind the dam and the overflow will be controlled by the limited pipe capacity. The net result is that these detention dams will effectively slow and control the rate of outflow over time within

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[4] The runoff factor, C, can actually increase slightly with increasing rainfall intensity. For the sake of this course assessment, we have assumed a constant C.

the subdivision. The same is true for storm runoff leaving the gullies at the gully outlets labelled A-out, B-out, C-out and D-out.

Figure 6.2: 5 year 20 minute Storm Outlet Flows for 2001, 2030 and 2080

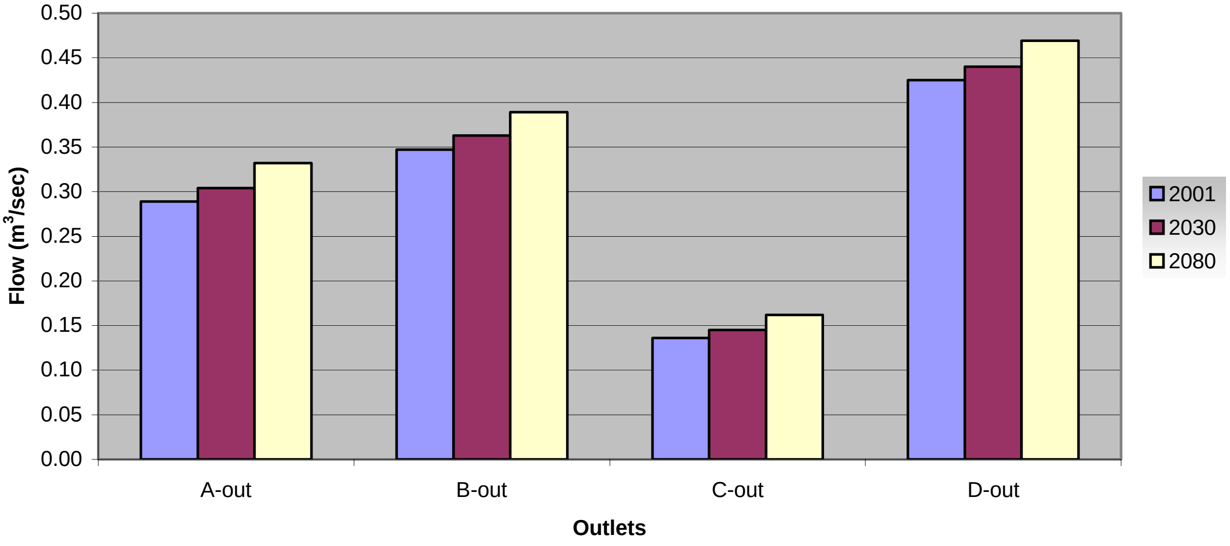


Figure 6.2 shows the increase in flow at each of the four gullies during the three key dates 2001, 2030 and 2080.

Figure 6.3: 50 year 20 minute Outlet Flows for 2001, 2030 and 2080

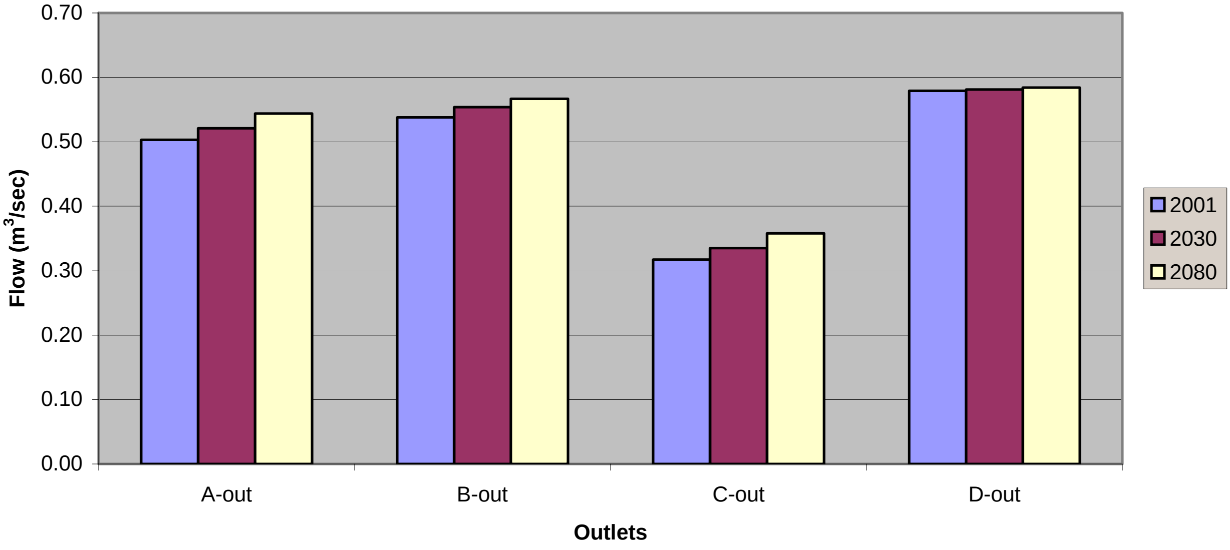


Figure 6.3 shows the increase in flow at each of the four gullies during the three key dates 2001, 2030 and 2080.

Figure 6.4: five year 20 minute Storm
Basin Water Depths for 2001, 2030 and 2080

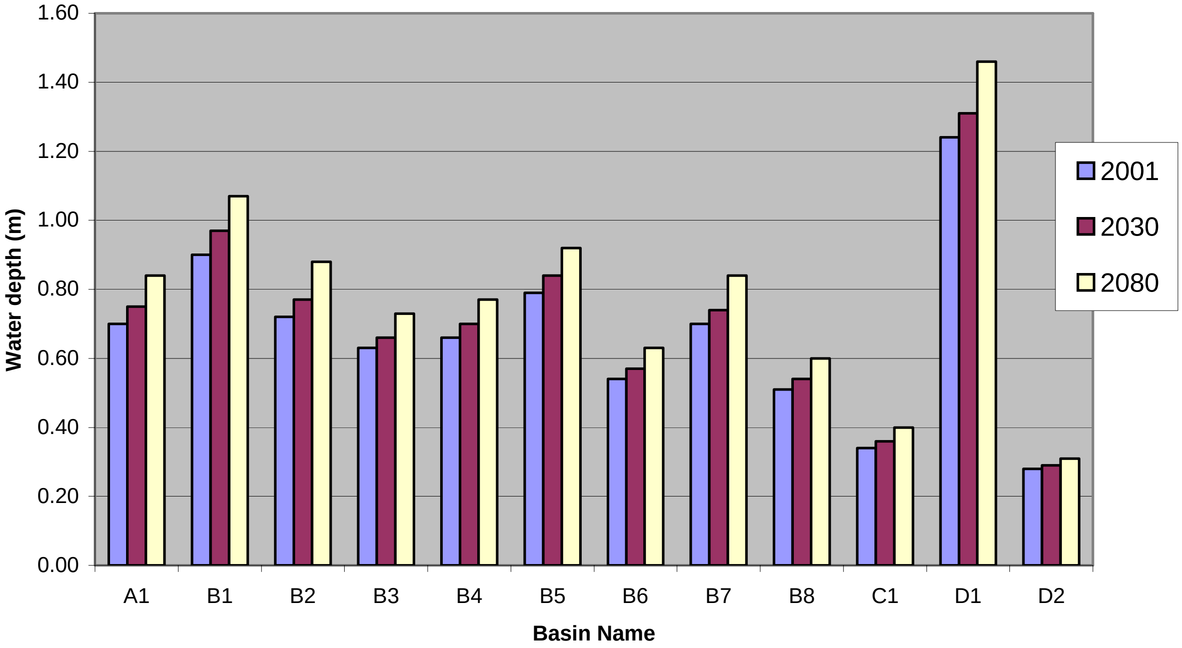


Figure 6.4 shows the depth of water behind each detention dam in the present and future scenarios for the 5 year event.

Figure 6.5: 50 year 20 minute Storm
Basin Water Depths for 2001, 2030 and 2080

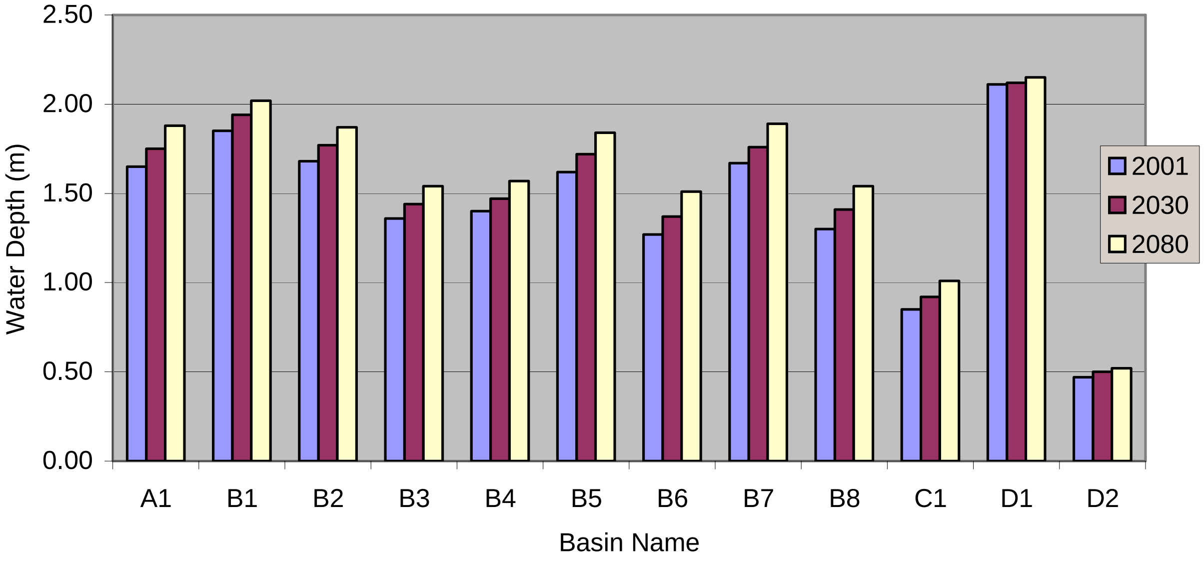


Figure 6.5 shows the depth of water behind each dam in the present and future scenarios for the 50 year event.

Note that the preliminary detention dam design called for a generic design of 2 m detention dams and 450 mm diameter culvert pipes. These could have been individually sized to optimise flow conditions and ponding depths and to provide an additional margin of safety. This was to avoid costly design and specification for each site and also to emphasise the softer, less designed feel of uniform landscaped mounds rather than engineered dams.

Key findings for the upper catchment:

- Even when the more severe 2030 and 2080 storms are applied over the catchment the dam water will not spill over the 2 m high detention dams in events not exceeding 50 years. However, the effect of climate change is to increase the likelihood of spilling. Where in the past spilling may have occurred in a 100 year event for detention dam D the same may occur in say a 70 year event in 2030 or 2080. If all detention dams were designed to be close to their ponding depth for a 50 year 2001 event, then 2030 and 2080 scenarios of spilling (depth exceeding 2 m) are likely to occur much more frequently. In other words, climate change would lower the level of protection and increase flood risk.
- The average (over all the dams) maximum depth change for a five year event is 6% for 2030 and 18% for 2080. In a 50 year event the increases are 6% for 2030 and 13% for 2080. The following table illustrates how the factor of safety against dam overtopping reduces in 2030 and 2080 for both the five year and 50 year events. The factor of safety has been averaged over all dams.

Table 6.1 Average factor of safety against dam overtopping in the upper catchment

Year / **Rain Event**	**2001**	**2030**	**2080**
Five year 20 minute	2.5	2.3	2.0
50 year 20 minute	0.6	0.5	0.4

Note that the assessment of the change in flood risk and its effect on safety margins is limited by some uncertainty in the rainfall base data. This data was extrapolated from historic records and used to estimate 50 and 100-year return periods. We estimate that the proposed detention dams, culverts and housing development in all cases provide a sufficient margin of safety to accommodate the uncertainty of the current actual flood risk.

6.2 Findings for the Lower Catchment

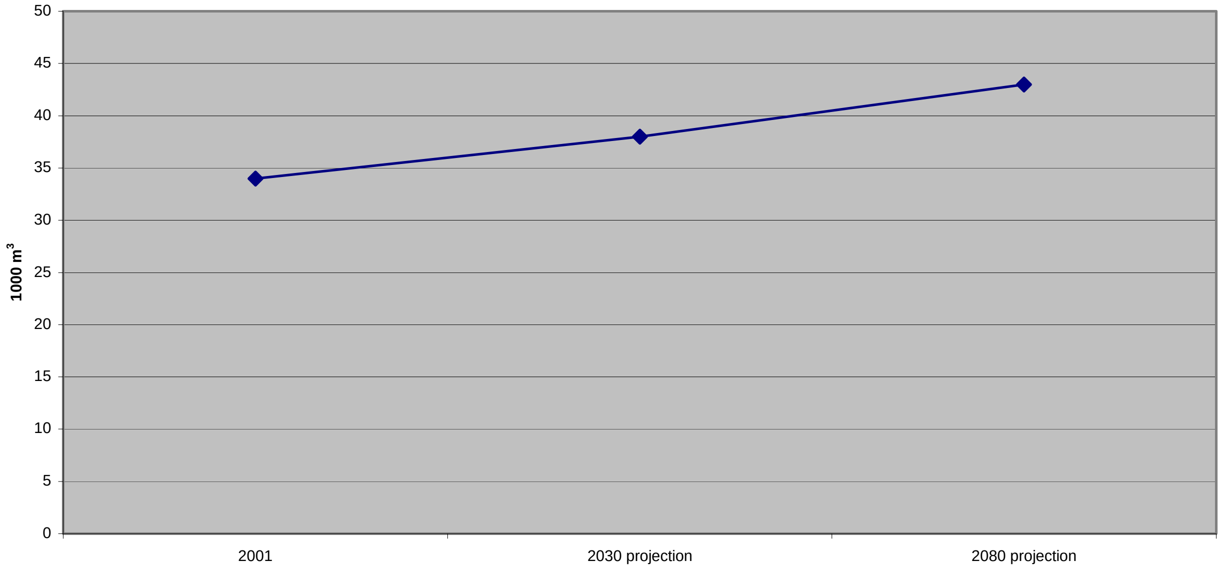
Key findings for the lower catchment:

- Assuming no change in landuse, the projected total catchment runoff volumes produced for the area modelled are 13% and 28% more than the existing case for 2030 and 2080 respectively. These are in line with the projected rainfall depth increase.

- The maximum increase in flood inundation depths in various basins for 2030 is up to 60 mm and for 2080 is up to 120 mm.
- The rainfall increases are based on the maximum temperature increase, and therefore, the result represents the worst case or upper bound scenario.

This catchment was first modelled in 2001 prior to proposed development of the upper catchment. The effect of development proposals (as discussed in Section 6.1) will be to change the runoff volumes exiting from this catchment. However, for comparison purposes we have remodelled this catchment by changing projected future rainfall changes only. All other data have been left unchanged.

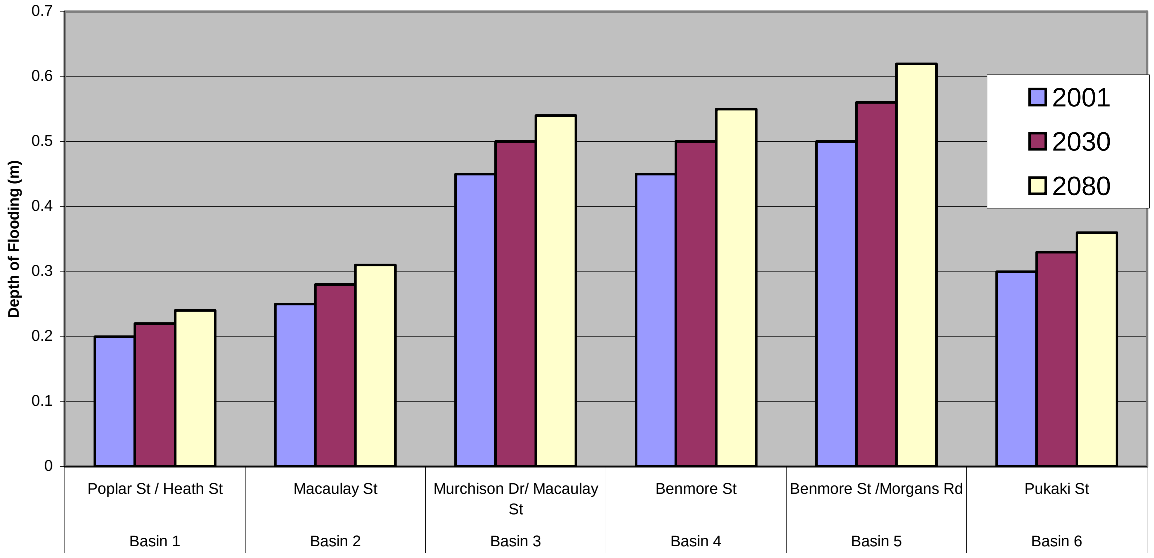
Figure 6.6: Total catchment runoff volumes in a 50 year one hour event



The results show that the projected increases in flood inundation for 2030 is up to 60 mm and for 2080 is up to 120 mm. The durations of flooding, which have been calculated to the nearest 15 minutes, have generally remained the same (see Figure 6.8).

As stated earlier, the modelled runs are based on the assumption of no change in the land use and development. Therefore the results are based on change in the rainfall only; all other factors were assumed to be the same.

Figure 6.7: Flood inundation basins 1-6 in a 50 year one hour event



The key findings are:

- The projected increase in the rainfall for 2030 and 2080, due to climate change is expected to be 13% and 28% respectively with respect to the existing design rainfalls for 50 year one hour rainfall events.
- Assuming no change in land use, the projected total catchment runoff volumes produced for the area modelled are 13% and 28% more than the existing case for year 2030 and 2080 respectively.
- The maximum increase in flood inundation depths for 2030 is up to 60 mm and for 2080 is up to 120 mm.

With the increase in the residential development, the runoff volumes will increase. At this stage, we suspect they will not significantly worsen because of the type of stormwater treatment proposed. As mentioned, the series of detention dams and culverts will control flows to the lower catchment.

Table 6.1. Predicted Flood Hazard Summary – 50 year 1hr event: 2001, 2030 and 2080.

Subcatchment	2001		2030		2080	
	Approx. Property Damage	Flood Depth (m)	Approx. Property Damage	Flood Depth (m)	Approx. Property Damage	Flood Depth (m)
Basin 1 *Poplar St / Heath St*	-	0.20	-	0.22	-	0.24

Basin 2 *Macaulay St*	-	0.25	-	0.28	-	0.31
Basin 3 *Murchison Dr / Macaulay St*	-	0.45	-	0.50	-	0.54
Basin 4 *Benmore St* (*between Monowai* St and Waipori Place)	-	0.45	-	0.50	-	0.55
Basin 5 *Benmore / Morgans St*	1	0.50	1	0.56	1	0.62
Basin 6 *Pukaki St*	-	0.30	-	0.33	-	0.36

6.3 House Floor Levels and Freeboard

In order to quantify the potential flood damage, we compared the predicted flood levels from the model to the actual house floor levels (in flood hazard areas). See Appendix C for further background.

Freeboard is a word to describe the extra depth of floodwater, which is added to the calculated flood depth. It is a factor of safety to cover uncertainties. There are many uncertainties associated with converting a design rainfall into a stream flow and routing it down a pipe or channel. We have allowed 0.5 m freeboard (see Appendix C for further background).

6.4 Recommendations

It is important to note that the flow rates and depths are generated from projected **upper bound** rainfall depth predictions. If these rainfall changes occur as predicted, the net result is that stormwater assets designed today should have a greater in-built factor of safety than is currently used. Most stormwater pipes, drains and structures should be designed for a minimum life of 50 years.

However, the most likely future scenario is a matter of conjecture. It may be more reasonable to use an increase in rainfall depth, which is midway between no change and the upper bound estimate. For planning purposes, it may be most practical to plan as a minimum for the midway between no change and the upper bound scenario. For other planning situations, if an initial screening analysis suggests that margins of safety could be substantially reduced or even breached due to climate change, the full range of future scenarios should be explored and a more complex analysis of future changes in heavy rainfall and return periods may be required.

We recommend that:

1. **Climate change research continues so that the rainfall predictions for Timaru may be further refined. The findings in this study are based on an initial screening analysis and our conclusions are qualified by uncertainties in the current distribution of heavy rainfall events for the catchment in question.**

2. **In the meantime, assets with design life exceeding 50 years should be designed using at least half the upper bound predicted rain depth increases. This equates to 6% for the 5 year event and 14% for the 50 year event in the Canterbury region.**

3. **There is no change to the proposed stormwater system for the Gleniti development. The in built margin of safety is large enough to accommodate the expected increase in heavy rainfall events even for the upper bound of expected changes. The same applies to the lower catchment.**

7 Analyse Risks - Likelihood and Consequences (Costs) of Flooding

In this section, we discuss the flood risk in terms of likelihood and consequence and make recommendations for future stormwater design.

7.1 Introduction

The concept of 'flood risk' is made up of two components – the likelihood of the flood occurring (whether it be five or 50 year or any other event) and the consequence if it does occur. These are discussed in the following sections. See Appendix B for a discussion on risk likelihood.

7.2 Floods Greater Than The Design Standard

In any single year there is a small possibility (2%) of flooding occurring that surpasses the 50 year flood. The Maximum Probable Flood[5] for Timaru City is estimated to have a return period of around 2,000 years (0.05% chance of occurring in any single year). No assessment of this event has been carried out. However, it is fair to say that this would be a high consequence/low probability event.

7.3 Consequences (Costs) of Flooding

A major flood in Gleniti could cause millions of dollars worth of damage to property and community assets. The social and psychological costs, although difficult to quantify, would compound the devastation.

The flood hazard maps show the inundation expected in a 50 year storm. The following tables show the potential damage arising from each of these storms.

7.3.1 Damage Costs

The cost of damage for various risk categories are based on an estimation of the resources required to clean up after a flood and to rebuild property and Council assets. The repair costs were estimated, based on:

- land area of affected property
- likely property repair costs
- likely council asset repair costs (roads, drainage features, underground services, etc).

We understand from work done by Loss Adjusters[6] (specialising in flooding losses), that they generally expect 50-60% general household chattel loss, all wall lining and electrical, some window, door and other miscellaneous losses.

The total household loss on average is $85,000.

Roading and services costs were estimated at 10% of the cost of replacement of road, power, phone and water reticulation. A figure of $40/lineal m was used.

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[5] The flood arising from the largest theoretically possible storm for Timaru City.

[6] See 2001 report

7.3.2 Disruption Costs

Indirect flood losses are those that occur through interruption and disruption of economic and social activities, as a direct consequence of flood damage (see 2001 report). These include the disruption of business, disruption of production, traffic diversion and disruption costs, damage to services, disruption of households and the costs of emergency services.

The report on potential damages in the Hutt Valley (See 2001 report) uses a set of multipliers for indirect damage, which were evaluated, in the Brown, Copeland and Co. report[7]. The Hutt Valley report notes that the indirect costs include lost productivity for one to three weeks of downtime in industrial and commercial premises, and are based on a multiplier of two on wages and salaries. This would make some allowance for traffic diversion and disruption costs. The total cost makes no allowance for damage to streets and services. The factor used for residential property is 15%. For an $85,000 loss, this equates to $12,750.

7.3.3 Total Economic Costs of Damage

Total economic costs of damage during the various storm events have been estimated for each location. The total economic cost includes the damage reinstatement cost as well as the traffic disruption cost and consequential costs such as business interruption costs.

The estimated total economic cost is calculated for a 50 year return period storm in 2001, 2030 and 2080.

These are shown in Table 7.1 below and the key data is:

- *2001:* Total losses for the critical 50 year design storm are around $106,000
- *2030:* Total losses for the critical 50 year design storm are around $106,000
- *2080:* Total losses for the critical 50 year design storm are around $106,000

7.4 Cost Summary

The increased rain depths projected for 2030 and 2080 cause flood depths, flows and volumes to increase in both the study catchments. However, the increases aren't significant enough to cause an increase in damage costs. In all three scenarios only one property is damaged. The reasons for this may be unique to each catchment and are discussed below.

In the **upper catchment**:

- The detention dams are all designed at a generic height of 2m. This allows a reasonable freeboard in most cases. For example, the maximum depth of water backing up behind detention dam C1 is around 1m and many of the others is around 1.2-1.7m.

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[7] Economic Assessment: Proposed Waimakariri Flood Protection Works, Brown, Copeland & Co Ltd, November 1982.

- The discharge culverts are all a generic 450 mm diameter. These could have been individually sized to optimise flow conditions and ponding depths.
- The proposed housing developments will be well set back from the waterway gullies. Therefore, any flooding that would occur from within the gully/detention dam system due to an extreme rain event is unlikely to cause property damage.

The net effect of these three design features is to build in a factor of safety. As discussed in Section 6, if the design had only allowed for an appropriate freeboard by today's standards then this catchment would suffer an increased flood risk in 2030 and 2080.

In the **lower catchment**:

- The projected flood depth increases of 60 to 120 mm in 2030 and 2080 respectively are not significant enough to threaten any more properties than in 2001. In many cases, the habitable spaces in potentially threatened houses are sufficiently elevated from the basins.

As with the upper catchment above, the effect of raised houses is to build in a factor of safety. There may be existing flood basins in other parts of Timaru, which are 'right at the limit' with only a minimal factor of safety. It is these areas that would suffer an increased flood risk in 2030 and 2080.

Table 7.1. Total Economic Damage in 2001, 2030 and 2080 for a 50 Year Design Storm

2001						
Basin	**50 year/20 metre event**					
	Residences		**Road (m)**			
	Approx. number	**Cost ($85,000 per residence)**	**Length (m)**	**Cost ($40/m)**	**Indirect cost (15% of residential cost)**	**Total**
5	1	85,000	200	8,000	12,750	105,750
Totals						
2030						
Basin	**50 year/20 metre event**					
	Residences		**Road (m)**			
	Approx. number	**Cost ($85,000 per residence)**	**Length (m)**	**Cost ($40/m)**	**Indirect cost (15% of residential cost)**	**Total**
5	1	85,000	200	8,000	12,750	10,5750
Totals						
2080						
Basin	**50 year/20 metre event**					
	Residences		**Road (m)**			
	Approx. number	**Cost ($85,000 per residence)**	**Length (m)**	**Cost ($40/m)**	**Indirect cost (15% of residential cost)**	**Total**
5	1	85,000	200	8,000	12,750	105,750
Totals						

Note that for simplicity the 2030 and 2080 costs are calculated in 2001 dollars and have not been adjusted for net present value.

Appendix A
Modelling Background

Flood Hazard Modelling

Introduction

The existing MOUSE model of the Waimataitai catchment was used for the flood hazard assessment using the year 2030 and 2080 rainfall projections. The existing model was originally constructed in 1998-99 for the flood hazard assessment and mitigation study in the Waimataitai catchment for the Timaru District Council. In the original study, the whole Waimataitai catchment was modelled using four MOUSE models draining into one MIKE11 model. The scope of this study is to assess the affect of projected rainfalls in the area covered by first model only i.e. the area between the top of the catchment up to Glenfield Avenue, as shown in Figure 6.1a of the "Flood Mitigation Study for Waimataitai Catchment, Timaru City (August 2001)", included in this report as Appendix 1.

Key changes made to the existing model were:

- The original catchment model was constructed using the MOUSE 1999 version. It was converted to MOUSE 2000b version, as Opus currently runs only 2000b or later versions of the MOUSE models.
- The input rainfall hyetographs for 50 year and 100 year return periods were updated for the projected 2030 and 2080 rainfalls.

Modelling Assumption

The following assumptions were made for the modelling runs.

- The level of development for the future scenarios (year 2030 and 2080) was assumed to be exactly the same as modelled originally.
- Critical storm duration and storm pattern were assumed to be the same as in the original model.
- Temporal distribution of the rainfall was also assumed to be the same.

In essence, the modelling runs carried out in this study compare the effects of the projected rainfalls assuming all the other factors to be exactly the same. Critical storm duration for the area modelled in this study is one hour (as originally), therefore the modelling runs were carried out for 50 year and 100 year return periods for one hour storm duration.

Rainfall Hyetographs

The projected rainfall tables presented earlier in section 2 show that percentage increases in the one hour rainfall for the years 2030 and 2080 are 13% and 28% respectively with respect to the current design rainfalls. Assuming the same temporal pattern the rainfall hyetographs for years 2030 and 2080 were developed as shown in Figures 3.1 and 3.2 respectively.

Modelling Results

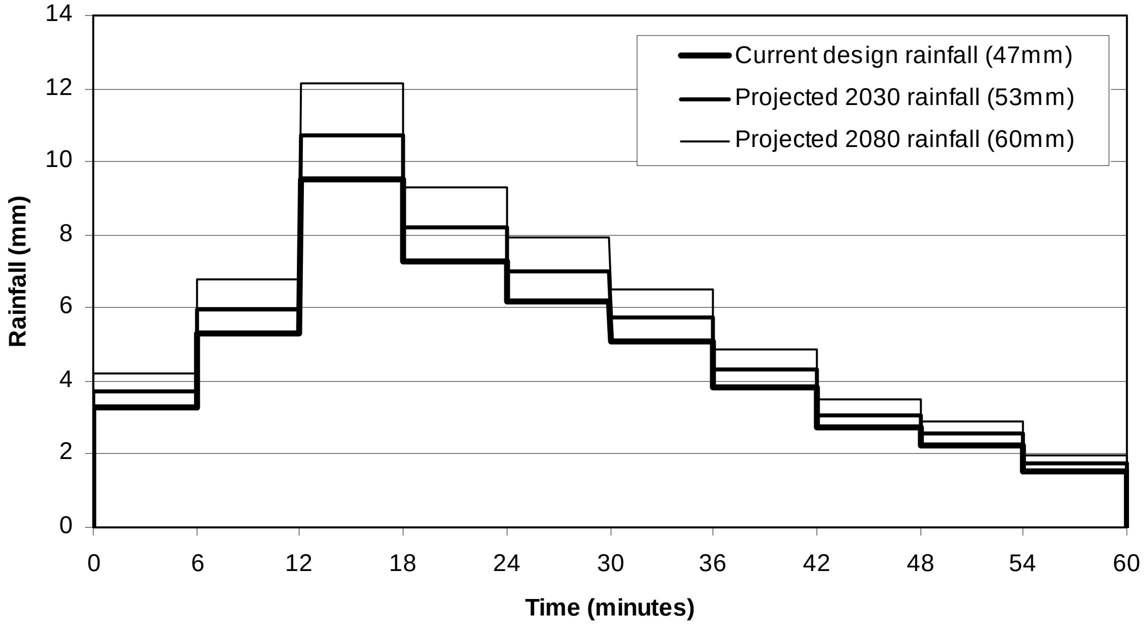

Figure 3.1 50 year 1 hour duration rainfall hyetographs for Timaru

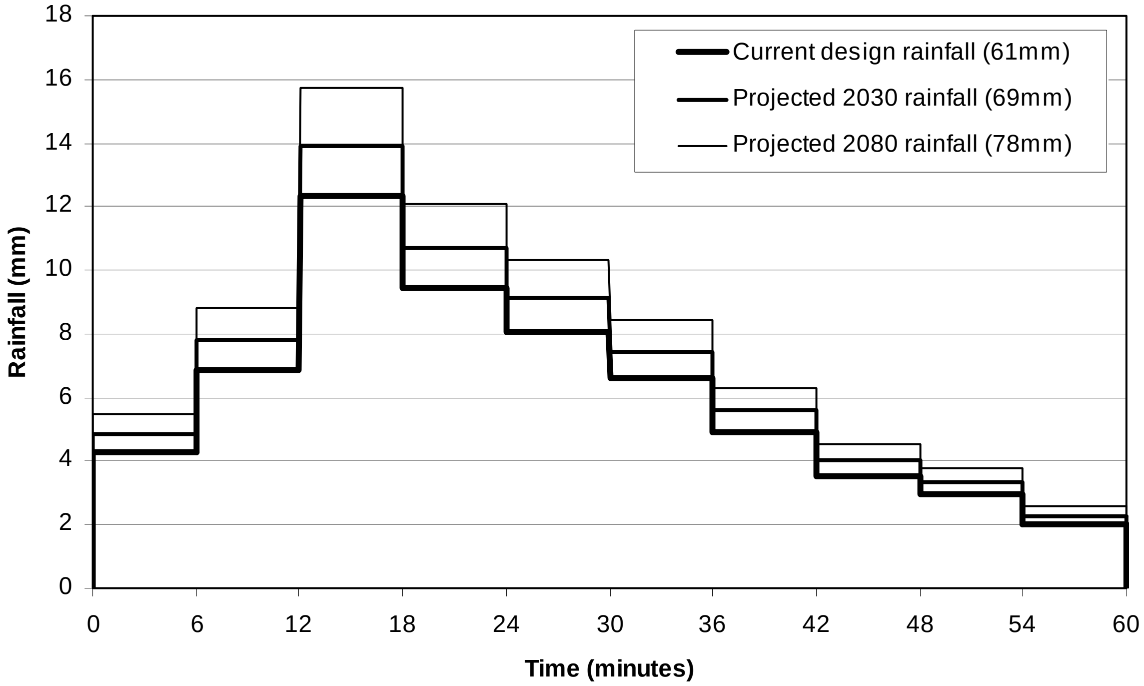

Figure 3.2 100 year 1 hour rainfall hyetographs for Timaru

After converting the original MOUSE model from the 1999 version to the 2000b version, a base case run was carried out to compare and reproduce the original results using the one hour 50 year and 100 year return period rainfalls respectively. The converted model showed some instability at the downstream end near the Glenview Street area, other than that the results produced were very similar to the original results.

Having compared the base case results with the original results, the input boundary conditions were modified to include the projected rainfall hyetographs for year 2030 and 2080 for each 50 year and 100 year return period respectively. The model was then rerun for each case.

The total catchment runoff volumes produced in each case are summarised in Table B.3.

Table B.3 Catchment runoff volumes for each modelled run

Case Modelled	One hour 50 year rainfall		One hour 100 year rainfall	
	Runoff volume (m^3)	% Increase from the base case	Runoff volume (m^3)	% Increase from the base case
*Base Case	33,513	-	44,836	-
2030 projection	37,925	13%	50,702	13%
2080 projection	43,064	28%	57,324	28%

** Base case refers to the modelling run based on the current design rainfalls*

Note that the percentage increase in the runoff volumes produced are the same as increase in rainfall depth i.e. 13% and 28% for 2030 and 2080 respectively. This is expected to be the same because the catchment runoff coefficients have not been altered for future scenarios.

A comparison of the depths of flood inundation produced for the base case, i.e. the existing design rainfalls for one hour 50 year and 100 year rainfalls are summarised in Table B.2. These results are the same as produced originally and the 'basins' referred to are as shown in Figure 6.1a of the 2001 report.

Table B4 Existing flood inundation for one hour duration 50 year and 100 year storm events (Base Case)

Location		One hour 50 year rainfall		One hour 100 year rainfall	
		Depth of flooding (m)	Flood duration	Depth of flooding (m)	Flood duration
Basin 1	Poplar St / Heath St	0.20	0 hr 45 min	0.25	1 hr 0 min
Basin 2	Macaulay St	0.25	0 hr 45 min	0.30	1 hr 0 min
Basin 3	Murchison Dr/ Macaulay St	0.45	1 hr 15 min	0.55	1 hr 30 min
Basin 4	Benmore St	0.45	1 hr 15 min	0.50	1 hr 30 min
Basin 5	Benmore St /Morgans Rd	0.50	1 hr 15 min	0.50	1 hr 30 min
Basin 6	Pukaki St	0.30	1 hr 30 min	0.40	1 hr 30 min

The projected depths of inundation for year 2030 and 2080 are summarised in Tables B.5 and B.6 respectively.

Table B.5 **Projected flood inundation for one hour duration 50 year and 100 year storm events for year 2030**

Location		One hour 50 year rainfall		One hour 100 year rainfall	
		Depth of flooding (m)	**Flood duration**	**Depth of flooding (m)**	**Flood duration**
Basin 1	Poplar St / Heath St	0.22	0 hr 45 min	0.27	1 hr 0 min
Basin 2	Macaulay St	0.28	0 hr 45 min	0.33	1 hr 0 min
Basin 3	Murchison Dr/ Macaulay St	0.50	1 hr 15 min	0.60	1 hr 30 min
Basin 4	Benmore St	0.50	1 hr 15 min	0.56	1 hr 30 min
Basin 5	Benmore St /Morgans Rd	0.56	1 hr 15 min	0.56	1 hr 30 min
Basin 6	Pukaki St	0.33	1 hr 30 min	0.44	1 hr 30 min

Table B.6 **Projected flood inundation for one hour duration 50 year and 100 year storm events for year 2080**

Location		One hour 50 year rainfall		One hour 100 year rainfall	
		Depth of flooding (m)	**Flood duration**	**Depth of flooding (m)**	**Flood duration**
Basin 1	Poplar St / Heath St	0.24	0 hr 45 min	0.28	1 hr 0 min
Basin 2	Macaulay St	0.31	0 hr 45 min	0.36	1 hr 0 min
Basin 3	Murchison Dr/ Macaulay St	0.54	1 hr 15 min	0.64	1 hr 30 min
Basin 4	Benmore St	0.55	1 hr 15 min	0.62	1 hr 30 min
Basin 5	Benmore St /Morgans Rd	0.62	1 hr 15 min	0.62	1 hr 30 min
Basin 6	Pukaki St	0.36	1 hr 30 min	0.48	1 hr 30 min

Appendix B
Risk and Probability

Likelihood of Flooding

The object of this section is to discuss likelihood of various floods occurring.

The Concept of Return Period

Traditionally storm events and similar events such as earthquakes have been described in terms of their return period. This term is used to describe the event that may be expected to occur once on average during the return period. For example a 50 year storm could be expected once every 50 years on average. This will be true in the long term but in the medium term these events are unlikely to come on their return period anniversary. The higher the return period the more severe the event.

Stormwater runoff is generated following rain on a catchment. Some soaks to ground and the remainder runs off. As rainfall data records go back less than 200 years it is not possible to know whether our data is truly representative.

Table C.1 shows the situations where each return period is applied in stormwater reticulation design in Timaru (from the Proposed District Plan, *6.5.3.3 Performance Standards for Stormwater Design*) and in general in NZ through local authority codes and The NZ Building Code.

Table C.1: Stormwater Design Criteria Used by Timaru District Council

Return Period		**Proposed Timaru District Plan Cl 6.5.3.3**
Two years	Commonly taken to represent flow conditions that lead to long-term erosion characteristics. For example, providing flow attenuation so that 2-year flows remain unchanged should control stream bank migration.	
Five years	Surface flooding on yards, carparks, etc. Piped systems are designed for this standard.	In these zones: Recreation Rural Residential zones 1-5
5-10 years	Minimum standard for new residential primary systems (with an acceptable secondary system for more severe events).	These zones for 10 year return periods: Industrial Commercial
20 years	Minimum standard for new commercial primary systems	

	(with an acceptable secondary system for more severe events).	
50 years		Acceptable when using a secondary flow path
100 years	Minimum standard for protection of habitable dwelling floors and commercial premises floors.	

Inevitably, storm conditions will occur sooner or later that exceed the primary (e.g., the underground piped system) capacity deliberately designed into a solution. In every case therefore, two systems must be considered: the primary system and the so-called secondary flow (or overland flow) system.

The fact that two systems are in operation is an aspect often poorly understood by the general community and particularly by anyone suffering the consequences of past stormwater management decisions. The risk that one or both these systems will fail to cope during their lifetime is therefore an important aspect that needs clear understanding.

Probability Examples

Predicting random events such as flooding is obviously an approximate science. These examples may help put risks of flooding in Timaru into context:

Burglary in any one year	1 in 16
Flood protection for commercial properties	1 in 20
Drawing the ace of spades in any one draw	1 in 52
Protection required to property under the NZ Building Code	1 in 50
Infant mortality	1 in 119
Contracting heart disease in any one year	1 in 1000
The 'Probable Maximum Flood.'	1 in 2000
Div 1 lotto win from a lucky dip in any one draw	1 in 400,000

Of course, it is possible to get two or more 50year floods in quick succession, in the same way as it is possible to consecutively draw two ace of spades in a properly shuffled pack of cards.

Lifetime Risk

The probability that lifetime events will occur during some period of time such as during their ownership of a dwelling or over their lifetime is of more relevance to the community than return period values.

The following table shows the probability of an event occurring over a given period of time.

Table C.2: Lifetime risk

Storm return period	Probability of occurrence over 5 year period	Probability of occurrence over 10 year period	Probability of occurrence over 50 year period	Probability of occurrence over 100 year period
Five years	67%	89%	100%	100%
50 years	10%	18%	64%	87%
100 years	5%	10%	39%	63%

For example, if a 40 year old house was built in a flood prone area, what would the probability be of it flooding in its lifetime? If the house (which might be expected to last for 70 years) had 30 years life remaining and the damaging flood was from a 50 year return storm, the probability would be 45%. Similarly, it would be 26% for a 100 year event.

Clearly, this has major implications for any house built-in a flood prone area in this catchment. Note that if a house in a hazard area has floor levels raised above the predicted flood waters (taking freeboard into account). The floodwaters will not inundate the living areas.

Appendix C
Background to Freeboard and Floor Levels

Likelihood of Flooding

House Floor Levels

In order to quantify the potential flood damage, we compared the predicted flood levels from the model to the actual house floor levels (in flood hazard areas). TDC surveyed the levels and noted whether the level referred to living space or garage/basement levels.

The 'property damage' referred to in Table 6.1 and Figure 6.1 has been determined as follows:

- A 'freeboard' level of 0.5 m is added to the predicted flood level from the MOUSE model. The concept of freeboard is explained below.
- Where the above level equals or exceeds the level of the living space, the property is assumed to be flooded.

Note that as this is a desktop study and all estimates of property damage needs to be confirmed 'on the ground.'

Freeboard

Freeboard is used to describe an extra depth of floodwater, which is added to the calculated flood depth. It is a factor of safety to cover uncertainties.

There are many uncertainties associated with converting a design rainfall into a stream flow and routing it down a pipe or channel. We have allowed 0.5 m freeboard to cover:

- Design rainfall and modelling uncertainties
- Wind and wave action on the water surface (wave action can occur as vehicles drive through floodwaters)
- Flood water and floor level comparisons. If floodwaters reach the bottom of the floor joists on a timber floored house (covers the majority of houses in flood hazard areas in this catchment) there is a possibility of water being wicked up and damaging habitable floor spaces.

All the quoted flood level depths used in this report exclude freeboard. However, to assess which houses would be damaged, we added 0.5 m freeboard to the flood level to get a critical flood level. If this critical level is greater than the surveyed floor level, then we have assumed that the habitable space will be flooded in the design storm event.